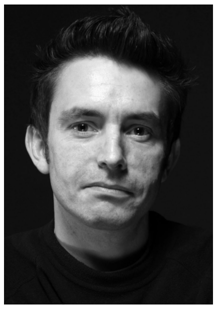
# IAQ and thermal comfort within a near EnerPhit retrofit of a historic house


Dr Carlos Jimenez-Bescos
Director Professional Doctorate
Anglia Ruskin University
United Kingdom
Carlos.JimenezBescos@anglia.ac.uk



Robert Prewett
Partner
Prewett Bizley Architects
United Kingdom
*rp@prewettbizley.com*

Dr Robert Cohen
Technical Director
Verco
United Kingdom
robert.cohen@vercoglobal.com



## Summary

This paper follows on two previous papers presented at the International Passivhaus Conference 2010, Whole house refurbishment in a Conservation Area, in Dresden and 2012 in Hanover, C80 Retrofit: Measuring is believing, in which the technical design data and preliminary energy use was presented.
The aim of this study was to evaluate the thermal comfort and Indoor Air Quality (IAQ) of the near EnerPHit dwelling while looking into how Passivhaus standard can achieve these targets while minimising energy consumption to draw lessons, which can be implemented in future Passivhaus and EnerPHit projects.
The approach chosen to monitor IAQ and thermal comfort was based on monitoring the following indoor hygrothermal conditions: internal air temperature, relative humidity (RH) and $CO_2$ concentration. Sensors were placed in every room of the dwelling for temperature and relative humidity and on the outside of the property to record outdoor conditions during the monitoring period. $CO_2$ concentration was measured in the kitchen and main bedroom.
This study shows that by applying the EnerPHit standard to retrofit projects, a healthy Indoor Air Quality and successful provision of thermal comfort for the occupants can be achieved during the winter season. Monitoring of the dwelling currently continue and further assessments regarding IAQ and thermal comfort will take place regarding the overheating aspects of thermal comfort in the summer months.
High carbon reductions can be achievable following the EnerPHit standard but furthermore, temperatures will be steady around 20 degrees, while relative humidity will be comfortably in between the range of 30% and 70% and $CO_2$ concentration levels will be well below the 1000 ppm as required for good air exchange and healthy IAQ.



**Keywords**: Indoor Air Quality; EnerPHit; Passivhaus; Retrofit; Thermal Comfort; Temperature; Relative Humidity; $CO_2$ concentration

## 1. Introduction

EnerPHit standard is a marginally lighter version of the Passivhaus standard for application to retrofit projects to reduce energy consumption while delivering thermal comfort. It can deliver massive reductions in terms of carbon dioxide emissions as previously reported by Cohen and Prewett [1] with a reduction of 84% on $CO_2$ emissions for an old mid-terrace dwelling, built in 1830 near Central London in a Conservation Area. Details of the near EnerPHit retrofit as been previously reported, in terms of the construction details and retrofit approach [2], and furthermore, in terms of the energy monitoring of the dwelling and Photovoltaic system [1].

In the current climate, with more and more EnerPHit standard and low energy retrofits taken place in UK, questions are being asked regarding the Indoor Air Quality (IAQ) and thermal comfort experience by Passivhaus occupants.

The aim of this study was to evaluate the thermal comfort and Indoor Air Quality (IAQ) of the near EnerPHit dwelling while looking into how Passivhaus standard can achieve these targets while minimising energy consumption to draw lessons, which can be implemented in future Passivhaus and EnerPHit projects.

## 2. Method

The approach chosen to monitor IAQ and thermal comfort was based on monitoring the following indoor hygrothermal conditions: internal air temperature, relative humidity (RH) and $CO_2$ concentration. Sensors were placed in every room of the dwelling for temperature and relative humidity, as shown in Figure 1, and on the outside of the property to record outdoor conditions during the monitoring period.

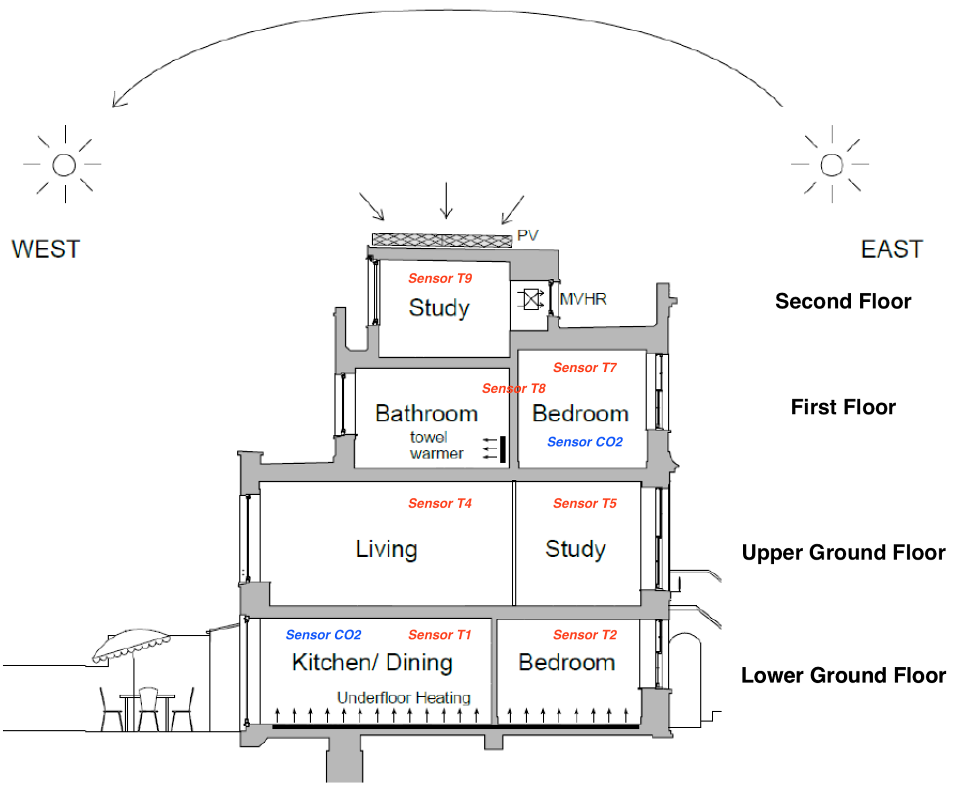



*Fig. 1 Sensor location. Temperture and relative humidity in red and $CO_2$ in blue. Adapted from Cohen and Prewett [1]*

The internal air temperature and relative humidity was recorded using a Perfect-Prime temperature and humidity data logger [3], with an accuracy of ±1°C, measurements were recorded with a one hour interval between readings. At least two sensors containing temperature and relative humidity were used to calculate the values of these variables for each floor are presented in Figure 1, only the second floor was using one sensor as there is only one room situated in that floor. It must be noted that although there was a data logger placed in the bathroom in the first floor, data from this sensor was not used to perform the average temperature and relative humidity of the first floor, as this would have skewed the results due to the higher temperature and relative humidity, which are normal to happen in bathroom. Instead a sensor was placed near the stairs in the first floor.

$CO_2$ concentration was recorded using a Trotec BZ30 $CO_2$ air quality data logger [4], with an accuracy of 5%, measurements were recorded with a 15 minutes interval between readings. Two sensors were used for $CO_2$ concentration, one placed in the kitchen in the lower ground floor and the other situated in the main bedroom in the first floor.

An important feature as seen in Figure 1 is that the dwelling has underfloor heating in the lower ground (kitchen and bedroom 2) and a heated towel rails in the bathrooms. Air from these zones will be extracted a used for the mechanical ventilation with heat recovery (MVHR) system with a 90% efficiency.

The study excluded the influence of air velocities due to having a draught free environment, achieved by the airtightness construction and careful design of the MVHR supply and extraction. In a similar way, radiation from internal surfaces was not considered, as the property achieves high internal surface temperatures with a temperature variation of less than 2.5 degrees. Furthermore, if air velocity and internal surface temperatures were to be monitored, they will have to be done in a very short period, mostly due to being too invasive for the occupants, hence not providing relevant data for the longer monitoring approach being targeted in this study.

## 3. Results

Following a trial and adaptation period since November 2016, data was collected continuously from all sensors for the period between 1st January 2017 and 12th March 2017.

Figure 2 illustrate the data

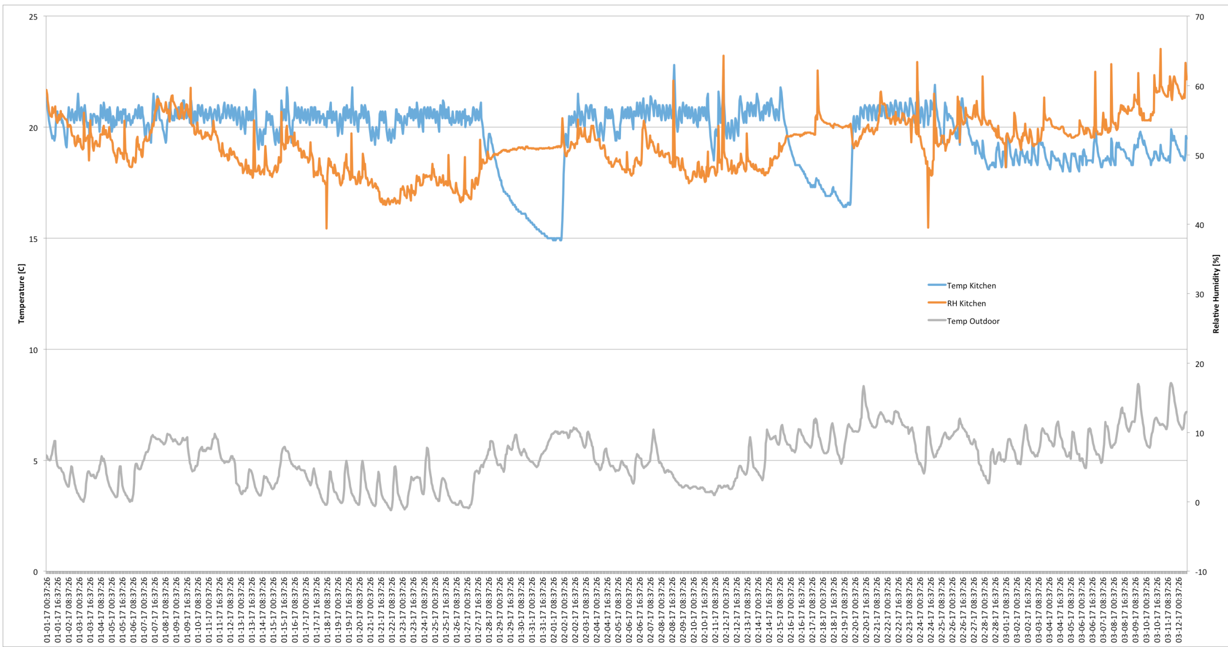



*Fig. 2 Temperature and relative humidity for the kitchen plus outdoor temperature during the monitoring period*

Regarding the data analysis for $CO_2$, temperature and relative humidity, the following process was applied:

- In terms of temperature and relative humidity, data was average for each floor in accordance to the sensor locations presented in Figure 1.
- CO2 data was taken directly form kitchen and bedroom.
- Frequency analysis was performed on all the data for a classification of temperature in accordance to lower than 18 degrees, higher than 22 degrees and one degree increments between 18 and 22 degrees. As the data was collected during the winter season, our priority was to identify if the dwelling is keeping its temperature at 20 degrees.
- Frequency analysis was performed on all the data for a classification of relative humidity in accordance to lower than 30% RH, higher than 70% RH and 10% RH increments between 30% and 70% degrees. According to McMullan [5], relative humidity should be kept between 30% and 70% to achieve thermal comfort.
- Frequency analysis was performed on all the data for a classification of $CO_2$ concentration in accordance to lower than 400 ppm, higher than 2000 ppm and 200 ppm increments between concentrations of 400 and 2000 ppm. Typical indoor spaces with good air exchange should not exceed 1000 ppm $CO_2$ concentration [6].
- Frequency percentages were calculated and plotted into the graphs presented in Figure 3.

# 4. Discussion

Figure 2 provides a graphical view showing how temperature were kept closely to the design temperature of 20 degrees and even when the underfloor heating is not working for five days, the dwelling has enough lag to maintain the temperature well above any condensation issues. Relative humidity oscillates between 40% and 60% but well below 70% values, avoiding any condensation issues associated with higher relative humidity.

## 4.1 Internal Air Temperature

As it is shown in Figure 3, temperature are very well kept around the 19-20 degrees areas with the following exceptions:

- Lower ground floor tends to be higher than any other floor due to the underfloor heating and the reliance of the upper ground floor to heat up with the air risen from the lower ground floor.
- The second floor shows a tendency to higher temperatures probably due to the rise of heat to the top floor by stack effect.
- The first floor presents lower temperature values, which are expected in bedroom for thermal comfort during the night.
- The Upper ground floor shows smaller temperatures than the design 20 degrees due to the lack of heating on that floor and the expectancy of heating risen from the underfloor heating below.

## 4.2 Relative humidity

All the floors are well kept between the comfort zones for relative humidity as shown in Figure 3, keeping the values between 30% and 70% relative humidity [5]. These values shown than the MVHR is performing a good task in controlling the fresh air intake into the property and releasing to the outside any generation of relative humidity to maintain a control environment.

## 4.3 $CO_2$ concentration

CO2 concentrations are shown in Figure 3 are very encouraging that the dwelling is able to provide to occupants a healthy environment with CO2 concentrations below 1000 ppm target [6] for over 95% of the monitoring period in the kitchen and over 85% for the bedroom. Such a healthy IAQ is the payback, which should be expected in low energy retrofit, in this case to the EnerPHit standard.


*Fig. 3 Temperature frequency data (top) and relative humidity frequency data (middle) for all floors and $CO_2$ concentration frequency for kitchen and bedroom*

# 5. Discussion

Figure 2 provides a graphical view showing how temperature were kept closely to the design temperature of 20 degrees and even when the underfloor heating is not working for five days, the dwelling has enough lag to maintain the temperature well above any condensation issues. Relative humidity oscillates between 40% and 60% but well below 70% values, avoiding any condensation issues associated with higher relative humidity.

### 5.1 Internal Air Temperature

As it is shown in Figure 3, temperature are very well kept around the 19-20 degrees areas with the following exceptions:

- Lower ground floor tends to be higher than any other floor due to the underfloor heating and the reliance of the upper ground floor to heat up with the air risen from the lower ground floor.
- The second floor shows a tendency to higher temperatures probably due to the rise of heat to the top floor by stack effect.
- The first floor presents lower temperature values, which are expected in bedroom for thermal comfort during the night.
- The Upper ground floor shows smaller temperatures than the design 20 degrees due to the lack of heating on that floor and the expectancy of heating risen from the underfloor heating below.

### 5.2 Relative humidity

All the floors are well kept between the comfort zones for relative humidity as shown in Figure 3, keeping the values between 30% and 70% relative humidity [5]. These values shown than the MVHR is performing a good task in controlling the fresh air intake into the property and releasing to the outside any generation of relative humidity to maintain a control environment.

### 5.3 $CO_2$ concentration

CO2 concentrations are shown in Figure 3 are very encouraging that the dwelling is able to provide to occupants a healthy environment with CO2 concentrations below 1000 ppm target [6] for over 95% of the monitoring period in the kitchen and over 85% for the bedroom. Such a healthy IAQ is the payback, which should be expected in low energy retrofit, in this case to the EnerPHit standard.

# 6. Conclusion

This study shows that by applying the EnerPHit standard to retrofit projects, a healthy Indoor Air Quality and successful provision of thermal comfort for the occupants can be achieved during the winter season, taking into account the limitations of this study: only one project monitored during winter months and the ideal occupants in terms of energy efficiency. Monitoring of the dwelling currently continues and further assessments regarding IAQ and thermal comfort will take place regarding the overheating aspects of thermal comfort in the summer months.

As reported by Cohen and Prewett [1], high carbon reductions can be achievable following the EnerPHit standard but furthermore, temperatures will be steady around 20 degrees, while relative humidity will be comfortably in between the range of 30% and 70% and $CO_2$ concentration levels will be well below the 1000 ppm as required for good air exchange and healthy IAQ.

# 7. References


[1] COHEN R., and PREWETT R., “C80 Retrofit: Measuring is believing”, *Proceedings of the 16$^{th}$ International Passivhaus Conference*, Hanover, 2012.

[2] COHEN R., and PREWETT R., “Whole house refurbishment in a conservation area”,

*Proceedings of the 16th International Passivhaus Conference*, Dresden, 2010.
[3] Perfect-Prime temperature and humidity data logger.Available at: https://perfect-prime.com/collections/data-logger-temperature-humidity-co2/products/th0160
[4] Trotec BZ30 $CO_2$ air quality data logger. Available at: https://uk.trotec.com/products/measuring-devices/climate/climate-data-loggers/bz30-co2-air-quality-data-logger/
[5] MCMULLAN R, "*Environmental Science in Buildings*", Palgrave, 2012.
[6] KANE International. Available at: https://www.kane.co.uk/knowledge-centre/what-are-safe-levels-of-co-and-co2-in-rooms